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EVALUATION OF AMMONIUM NITRATE, ALUMINUM MIXTURE (80/20)

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EVALUATION OF AMMONIUM NITRATE, ALUMINUM MIXTURE (80/20)

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ABSTRACT: An investigation of the chemical and physical properties of an ammonium nitrate/aluminum (80/20) mixture has been made. The sensitivity of the material to electrical, mechanical and thermal stimuli was determined. Other physical and chemical characteristics such as detonation rate, vacuum stability, and compatibility with various metals were determined. Although the mixture tested was less sensitive than many high explosives, the data as a whole was such as to lead to the conclusion that this material should not be used in electro-explosive devices.

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WHITE OAK, MARYLAND

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This report describes the results of an investigation of an explosive mixture (ammonium nitrate/aluminum, (80/20)) designated as TP-41. This work was performed in the Explosion Dynamics Division of the Explosions Research Department under NOL Task-409, Guided Missile Fuze Explosive Train Research.

This report describes laboratory results which should be of interest to personnel engaged in the design of explosive devices. The data are presented for information only and are not intended as a basis for action.

The identification of commercial materials implies no criticism or indorsement of these products by the Naval Ordnance Laboratory.

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By direction

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INTRODUCTION

1. Since World War II ordnance devices have gone through a revolution in concept and design. There has been a shift from conventional weapons such as guns, bombs, and projectiles to guided missiles, rockets, and super bombs. These new weapons have a destructive capability many times greater than conventional weapons. The complexity and destructive power of these new weapons require that a very high degree of safety and reliability be an inherent part of them. Many of the new weapons are using low energy conventional electroexplosive devices (EED's). It has been demonstrated that many of the low energy EED's can be initiated when subjected to RF and radar fields, static discharges and other spurious electrical signals. Since the new weapons are exposed to these environments one would naturally think of using very insensitive initiators to alienate the problems. Extending this idea further one could conceive of an initiator having a sensitivity of the same order of magnitude as the high explosive in the warhead or other high explosive in the weapon system. Such an insensitive device could also eliminate the need for a safety and arming mechanism. One way this could be accomplished is by the use of an insensitive explosive initiated by an Exploding Bridgewire (EBW). In this case ignition is accomplished by passing a large quantity of energy (approximately 1 joule) through the bridgewire in a very short time (approximately 1 microsecond) and literally exploding the bridgewire. The insensitive explosive could not be initiated merely by heating the wire slowly. Thus, by proper design accidental initiation by electromagnetic radiation could be eliminated.

2. Explosive mixtures have been developed commercially for initiation by EBW. One such mixture contains ammonium nitrate and aluminum powder (80/20) and has been designated TP-41. Ammonium nitrate has some desirable properties for use in EBW systems, (i.e. mechanical and electrical insensitivity and good thermal stability). Ammonium nitrate also has certain disadvantages such as:

(a) High hygroscopicity

(b) Unstable with certain metal impurities

(c) A crystalline phase change at 90°F with an accompanying increase in density

(d) A low detonation velocity

The use of ammonium nitrate in explosive devices therefore should be approached with caution.

3. The Naval Ordnance Laboratory, Corona, California (NOLC), requested that the Naval Ordnance Laboratory, White Oak (NOL/WO), investigate the sensitivity characteristics and thermal properties of the TP-41 mixture. As a result the following test program was devised and conducted.

(a) Sensitivity Study - Sensitivity of TP-41 to the following stimuli was determined:

(1) Impact

(2) Electrostatic spark

(3) Hot wire

(4) Exploding bridgewire

(5) 60 cycle A.C. current

(b) Study of the Thermal Properties - The following tests were conducted to determine the characteristics of TP-41 at elevated temperatures:

(1) Vacuum stability

(2) "Cook-Off"

(3) Sensitivity of molten TP-41 to EBW

(c) Chemical and Physical

(1) Chemical and microscopic analyses were conducted on TP-41

(d) Detonation Rate of TP-41 - The detonation velocity of TP-41 was measured with a smear camera at a density of 0.65 g/cc when initiated by an exploding bridgewire.

(e) The Ability of TP-41 to Initiate Secondary Explosives The ability of TP-41 to successfully initiate a column of CH-6 was determined.

(f) Supersensitivity - An investigation was made to determine the sensitivity of TP-41 when contaminated with various common metals, organic compounds, and chemically inert materials.[1/] A complete description of the impurities used is given in Appendix A.

1/ Bureau of Mines Report 1.C.7463 "Ammonium Nitrate. Its properties and Fire and Explosion Hazards", G. S. Scott and R. L. Grant June 1948.

(g) Reproducibility of TP-41 - Because of the limited amount of TP-41 made available to NOL/WO, several attempts were made to produce this material at NOL/WO. Two batches were prepared, and are designated as NOL TP-41 Batch 1, and NOL TP-41 Batch 2. Since no procedure for preparation was available, the first batch was made from ammonium nitrate and aluminum powder that was on hand. Later, the second batch was made using a procedure supplied by the commercial developer. However, because some of the equipment specified was not available several deviations in the procedure were made. For mixing details of NOL TP-41 Batch 1 and Batch 2, see Appendix B.

TEST PROCEDURES AND RESULTS

4. Impact Sensitivity Testing - The impact sensitivity of TP-41 was determined using a standard impact sensitivity machine.2/ Type 12 tools and a 2.5 kilogram weight were employed. Testing was conducted both on a bare anvil and with sandpaper on the anvil. The weight of material used per test was 35 milligrams and the criterion for an ignition was a flash and a report.

5. Three batches of TP-41 supplied by the commercial developer and two batches of TP-41 made at NOL were subjected to impact testing. The results of impact testing these batches, loose and in pellet form, are given in Table 1. The pellets, 3/16 inch in diameter, contained 35 milligrams of material pressed at 20,000 psi resulting in a density of 1.63 to 1.73 g/cc. The 50% impact height for the loose material, supplied by the commercial developer, varied considerably from 76 cm to > 320 cm (the limit of the machine). The pelleted material did not ignite and is reported as having a sensitivity greater than 320 cm. The material made at NOL also exhibited a wide dispersion, but not as great as that supplied by the developer. The results were 81 to 146 cm for the loose material and greater than 320 cm for the pellets. Comparison of the 50% heights of TP-41 with some of the more common explosives shows it to be less sensitive than tetryl and perhaps comparable to the more insensitive high explosives like TNT. At the time of this testing it was believed that the wide dispersion might be caused by the amount of moisture in the material. A test controlling the moisture content from zero moisture to 2.7% moisture was conducted. The results listed in Table 2 show that the TP-41 becomes progressively less sensitive as the moisture content increases. There was no indication of increased sensitivity from moisture.

2/ NavOrd 4236, "The Development of Impact Sensitivity Test at the Explosive Research Laboratory, Bruceton, Pa. During the Years 1941-1945"; Edited by H. Dean Mallory, 1956.

6. A second means by which it was believed TP-41 might become sensitized was by contamination with small amounts of metals (other than aluminum). Contamination could occur during normal handling and mixing. It was felt that the contaminating metals might react chemically with the ammonium nitrate forming complex salts and sensitizing the mixture. To test this theory mixtures containing 0.5% by weight of the following metals and compounds were added to various batches of TP-41 and NOL TP-41 and tested for sensitivity to impact:

Copper
Zinc
Magnesium
Tin
Nickel
Carbonyl iron
Silicon dioxide
Silicon carbide
Zirconium oxide

In addition, two organic compounds, benzoic acid and carnauba wax, were added to determine their effect on the sensitivity of the mixture. The results are given in Table 3. The data show that the impact sensitivities of the contaminated mixtures are about the same as the uncontaminated mixtures (Table 1).

7. Electrostatic Spark Sensitivity Testing - TP-41 Batch 1 was tested using the apparatus and test procedures described in NavOrd Report 6632[3/]. A metal to metal electrode system was used. In addition, tests were conducted on contaminated samples containing 0.5% by weight of the following metals:

(a) copper
(b) zinc
(c) magnesium
(d) tin
(e) nickel
(f) carbonyl iron

Two approaches were used. In the first, the maximum energy or voltage for non-ignition of the explosive mix was determined for six different capacitance levels: 0.01, 0.05, 0.10, 1.0, 2.0, and 4.0 microfarads. The second consisted of determining the percent initiation of the test sample at a given energy level for capacitances of 0.1, 1.0, and 2.0 microfarads.

8. For a given capacitance, the voltage was increased or decreased stepwise by 0.10 log units until an energy level was

3/ NavOrd 6632, "The Electrostatic Sensitivity of Bulk Explosives and Metal/Oxidant Mixtures", R. H. M. Wyatt, June 1959 (C).

attained for which 10 out of 10 samples failed to fire and for which the next higher test level resulted in at least one fire in ten trials. Table 4 lists the maximum no-fire energy so determined. Figures 1, 2, 3 present the data graphically. The data show that, for a given sample, as the capacitance is decreased and voltage increased, the energy needed for initiation decreases. This probably is due to the rate at which the energy is supplied. At the lower voltage, uncontaminated TP-41 is more sensitive than the contaminated samples, while at higher voltages the reverse is true. Static sensitivity was also determined with the capacitance held constant and the voltage varied. Three capacitors were used: 0.1, 1.0, and 2.0 microfarads. In this test the potential was increased in arithmetic steps. Table 5 summarizes the data. In the case of the 0.1 microfarad capacitor, the 100% fire point was unattainable because of the voltage limit of the test apparatus. The sample size is small and therefore, as one would suspect, the data is scattered. Minimum energy requirements to initiate the TP-41 are about one-half joule. The sensitivity to static spark appears to be independent of the capacitance. Comparison of the sensitivity of TP-41 with other common explosives (see reference 2) shows it to be less sensitive than PETN and more sensitive than tetryl.

9. Spark Gap Sensitivity - The static spark sensitivity of TP-41 Batch 2 was determined using the test fixture illustrated in Figure 4. The material was loaded at a density of 0.65 g/cc and the gap between the phonograph needles was set at 5, 10, 15, 20, 30, 40, 50, and 60 mils. The pulser contained a 5.0 microfarad capacitor and a variable voltage supply. Potentials ranging from 2.5 to 7.0 KV were used. The data, summarized in Table 6, show that an optimum gap for ignition was obtained at 50 mils. At this gap a minimum potential of 4.0 KV was necessary for initiation. Potentials lower than 3.0 KV were not effective at any of the gaps. Initiation was unreliable at the smaller gaps, becoming optimum at a gap of 50 mils. At this time, the sample of TP-41 Batch 2 was completely consumed and the testing was continued using TP-41 Batch 3. Under the identical conditions of testing as above, no initiations were observed over gaps ranging from 5 to 80 mils at 7.0 KV. The difference in spark gap sensitivity gives emphatic support to the difficulty in the reproduction of TP-41 mixtures.

10. Sensitivity to a Hot Wire - The effects of prolonged heating by a hot wire on TP-41 mixtures were not known. Since it is conceivable that an electrically initiated device, may be subjected for long periods of time to low level electrical power (such as by radar or radio waves) it is important to know the effects of such long term heating on safety and reliability. A series of tests was conducted to determine the effect of slow

heating. The TP-41 was placed loose on a 1.0, 5.0, or 8.9 mil diameter Tophet "C" wire. Heating of the wire was accomplished by either an AC or DC source. The current was applied for various lengths of time (0.75 - 10.0 minutes) until wire burn-out. Samples of TP-41 Batch 1 and TP-41 Batch 2 containing 0.5% of one of the following metals were also tested: copper, zinc, magnesium, nickel, tin, and carbonyl iron. The above materials were placed loose on the 8.9 mil diameter (wire 1.25 inches long). The current input (AC) was increased over a ten minute period to wire burn-out. In 5 out of 5 tests conducted on TP-41 Batch 1, no ignitions were observed. The contaminated samples gave the same results 2 out of 2 tests. However, molten beads of the material formed around the wire and moist red litmus paper turned blue when held over the material as it was being heated, indicating decomposition of the ammonium nitrate. TP-41 Batch 2 and NOL TP-41 Batch 2 were tested in the same manner. The results were the same with the exception that 2 out of 16 and 2 out of 9 samples, respectively, deflagrated. Additional tests were then conducted on TP-41 Batch 2 using a 1.0 and 8.9 mil diameter wire and a DC source. Deflagration did not occur in five tests with the 1.0 mil wire, while 7 out of 12 deflagrations occurred with the 8.9 mil wire.

11. In contrast to the slow heating methods applied above, the bridgewire was rapidly heated by capacitor discharge. A phenolic initiator plug having a pin spacing of approximately 50 mils was bridged with 5 mil diameter Tophet "C" wire. The same compositions previously tested were placed loosely in a phenolic ring attached to the plug and pulsed by the discharge of a 1.0 microfarad capacitor charged to 1,000 volts. In ninety tests no ignitions occurred. It appears from this testing that the material is more apt to ignite if heated slowly for a period of time as opposed to heating by capacitor discharge. This would indicate that the quantity of explosive heated and not temperature alone is important to ignition.

12. Sensitivity to Exploding Bridgewire - Sensitivity of the mixtures to an exploding bridgewire was determined by loading the material as illustrated in Figure 5. A phenolic plug was bridged with a 1 mil diameter Tophet "C" wire approximately 50 mils long and the material pressed onto the wire at densities of 0.65 and 1.0 g/cc. The assembly was confined in a gilding metal cup having a wall thickness of 10 mils. The pulsing apparatus consisted of a 1.0 microfarad capacitor and a variable voltage supply. The materials tested were TP-41 Batch 2 and NOL TP-41 Batch 2. In addition, the mixtures containing 0.5% of copper, zinc or magnesium were also tested. The criteria for an initiation consisted of the bursting of the cup, a flash, and a report. TP-41 Batch 2 at a density of 0.65 g/cc initiated 10/10 at 2000 volts. NOL TP-41 Batch 2 required 2500 volts to obtain

10/10 initiations at 0.65 g/cc. At a density of 1.0 g/cc TP-41 Batch 2 required 1000 volts to obtain 5/5 initiations while NOL TP-41 Batch 2 required 3500 volts to obtain 5/5 initiations. The metal additives to both mixtures appeared to raise the fire voltage. However, because the sample size was small, the results may not be significant. The data are summarized in Table 7. NOL TP-41 Batch 2 is more sensitive at 0.65 g/cc than at the 1.0 g/cc which was expected. The TP-41 Batch 2, however, was more sensitive at 1.0 g/cc than at 0.65 g/cc; again it is pointed out that the sample size is small which may account for the unexpected result.

13. Sensitivity to Alternating Current - To determine the effect of 110 volt, AC on EED's containing TP-41, detonators were fabricated which consisted of TP-41 Batch 2 in a steel cup loaded at a density of 0.65 g/cc and phenolic initiator plugs bridged with either 2 mil Tophet "C" or 1 mil platinum wire. The bridge length was approximately 50 mils. In addition, detonators, as above, containing PETN at a density of 0.88 g/cc were also fabricated. Three detonators of each group were placed directly across a 110 volt, AC line and in all cases ignitions occurred. It was not certain whether or not the material was detonating. Further testing was conducted varying the voltage in a Bruceton type method. Ignitions were observed for the following systems: 30 volts AC, 2 mil Tophet "C" wire and TP-41 at 0.65 g/cc; 40 volts AC, 1 mil platinum wire and TP-41 at 0.65 g/cc; and 50 volts AC, 2 mil Tophet "C" wire and PETN at 0.88 g/cc.

14. Determination of the Cook-Off Temperature of TP-41 The cook-off temperature of TP-41 Batch 2 was determined by two methods. The first method consisted of loading the material at 0.65 g/cc into an aluminum cup. The cup was closed by crimping a 10 mil thick aluminum disc at the open end as shown in Figure 6. The loaded cups were then dropped into a preheated oven for a period of time up to 15 minutes. In most instances, cook-off occurred in the first two minutes. The results of five trials each at various temperatures are given below:

Temperature (°F)	Cook-Off Observed
600	0/5
700	4/5
800	4/5
900	4/5
1000	5/5

A second test was conducted as above except that the TP-41 Batch 2 was loaded into a device simulating an electric detonator as shown in Figure 7. The results of this test are given below:

Temperature (°F)	NO Tested	Cook-Offs Observed
400	3	0
500	5	0
700	5	0
800	5	4
1000	2	2

Cook-off of TP-41 can occur at temperatures as low as 700°F for exposure times up to 15 minutes, when confined as above. This cook-off temperature is relatively high when compared to following explosives:4/

PETN	413°F
Tetryl	328°F
RDX	401°F

15. Sensitivity of Molten TP-41 - It was conceivable that a TP-41 loaded device being externally carried on fast flying aircraft could be aerodynamically heated to the melting point of the TP-41. Later, on cooling, TP-41 would solidify. The course of events might be such that it would be necessary to use the weapon at the time the TP-41 was molten, and therefore it would be desirable to know the sensitivity of molten TP-41. Or, if the TP-41 became molten, but the weapon was not used and later returned to its base, it would be necessary to know what effect the change from solid to liquid to solid had on the sensitivity and output of the TP-41. To determine the sensitivity of TP-41 Batch 2 in the molten state, detonators were loaded as shown in Figure 7. The TP-41 was loaded at a density of 0.65 g/cc about a 2-mil diameter Tophet "C" bridgewire welded to the pins of an initiator plug. The detonators were heated to 400° ± 24°F (the melting point of ammonium nitrate is 338°F) with individual furnaces consisting of an aluminum housing wrapped with insulating tape and nichrome wire as shown in Figure 8. The complete unit containing the explosive device was then heated and the temperature monitored with a thermocouple. When the desired temperature was reached (which required approximately 70 seconds) the device was pulsed by the discharge of a 1 mfd

4/ NOLR 1111, Ordnance Explosive Train Designers' Handbook, April 1952 (C)

capacicor. Fifteen unconditioned samples were pulsed at room temperature and fifteen in the furnaces at 400° ± 24°F. The results are tabulated below:

Sample Size	Temperature (°F)	Potential (volts)	Initiations
5	ambient	2500	5
10	ambient	2000	1
5	400 ± 24	2000	5
5	" "	1500	4
5	" "	1000	0

The results show that molten TP-41 is more sensitive than solid TP-41.

A second group of ten devices was conditioned for seven hours in a preheated oven at 450°F. On the assumption that the TP-41 became molten the samples were then withdrawn and allowed to cool to room temperature. Attempts were made to initiate them by the discharge of a 1 microfarad capacitor. At potentials of 2, 4, 5 kilovolts no initiations resulted. One device fired at 6 kilovolts. Resolidification of TP-41 appears to desenitize the mix. However, the long conditioning time may have resulted in considerable decomposition of the ammonium nitrate prior to the firing attempts.

16. Vacuum Stability Tests - The thermal stability of ammonium nitrate, TP-41 Batch 1 and TP-41 Batch 1 plus additives (one-half percent of magnesium, copper, zinc, nickel, tin, and iron), was determined by using the NOL vacuum stability apparatus[5]. The rate of gas evaluation was measured at temperatures of 150, 200, and 250°C. The sample size was 100 milligrams. At various intervals of time the volume of gas emitted at a given temperature was recorded and corrected to standard temperature and pressure. At 250°C, the volume change was too rapid to measure. Decomposition had to be recorded as an increase in pressure. The data obtained was plotted and the results are shown in Figures 9, 10, and 11. At 150°C ammonium nitrate was the most stable of the materials tested and TP-41 + 1/2% magnesium was the least stable. The samples of TP-41 containing magnesium, copper, zinc, and nickel were less stable

5/NavOrd Report 6629, "Improved Apparatus and Technique for the Measurement of the Vacuum Stability of Explosives at Elevated Temperatures(U)", Alvin H. Rosen and Herbert T. Simmons, 2 Mar 1959.

than TP-41, while those containing tin and iron were more stable than TP-41. At 200°C ammonium nitrate continued to be the most stable and TP-41 was the least stable. Samples of TP-41 plus copper, magnesium and zinc were less stable than ammonium nitrate in that order. At 250°C decomposition was fairly rapid. However, the trends observed were similar to those noted from other data in that TP-41 plus magnesium was the least stable while ammonium nitrate was the most stable. TP-41, TP-41 plus copper and TP-41 plus zinc had about the same decomposition rate. It would appear that the metal additives tend to catalyze the decomposition of ammonium nitrate.

17. Propagation Rate of TP-41 - The propagation rate of TP-41 Batch 2 was determined by means of a rotating mirror smear camera. The TP-41 was loaded at a density of 0.65 g/cc in a lucite cylinder having an I.D. of 0".261. A phenolic plug bridged with 2 mil Tophet "C" wire, 40 mils in length, and 35 mils above the plug surface was used as the initiator. The input energy was the discharge of a 1 microfarad capacitor at 5,000 volts. The writing speed of the camera was 0.877 millimeters per microsecond. Figure 12 illustrates the experimental set-up and shows the photographic record obtained from the test. The slit of the camera was aligned in a vertical plane with the spark gap in the lead wire and the plane of the bridgewire. The first indication of light on the record is the breakdown of the spark gap. Approximately six (6) microseconds later, the first evidence of the wire exploding was seen followed by a gradual build-up of the TP-41 to a terminal velocity of 2500 meters per second. A second test was conducted as above and the results were similar with the exception that the terminal velocity reached was 2725 meters per second.

18. The Ability of TP-41 to Initiate CH-6 - CH-6 is an explosive mixture of RDX, graphite, calcium stearate and polyisobutylene having an impact and shock sensitivity approximating that of tetryl. A test was conducted to determine if TP-41 initiated by an exploding bridgewire would cause CH-6 to detonate. The test detonator was designed to simulate existing detonator configurations. It consisted of a copper cup 0.260 ID., and 0.300 O.D. The initiator plug was bakelite bridged with 2 mil Tophet "C" wire approximately 40 mils in length. The cup was loaded with two increments of CH-6 and one increment of TP-41 Batch 2. The density of the TP-41 Batch 2 was approximately 0.6 g/cc. Its column length was 0".25. The first increment of CH-6 was loaded at a density of 0.8 g/cc (column length 0".41), and the second at a density of 1.2 g/cc (column length of 0".41). The input energy was by discharge of a 1 microfarad capacitor charged to 5000 volts. The criterion used to determine whether or not the CH-6 detonated was the depth of the dent obtained in a steel block. Twenty-four (24) tests were conducted and the

steel dent data obtained. The resultant dents ranged from 0 to 30 mils in depth. These data indicate that under the conditions tested the CH-6 did not consistently detonate. In addition, one would expect a much deeper dent from the amount of CH-6 loaded as evidenced by the 50 mil dent obtained when the same configuration of CH-6 was initiated by replacing the TP-41 with lead azide. A look at the photographic record in Figure 12 shows that the velocity for the first 0.25 length of TP-41 is low and obviously not high enough to initiate the CH-6 reliably.

19. Chemical Analysis - A chemical analysis was conducted on TP-41 Batch 2. The results of this analysis is given in Table 8.

20. Microscopic Study - A sample of TP-41 Batch 1 was studied under a microscope to obtain approximate particle size data. Many large particles which could very well be agglomerates were noted. Fine particles, which could be fragments of crystals were also noted. The particle size analysis is given in Table 9. The aluminum particle size is very small compared to the ammonium nitrate. Consequently, the size given is basically that of the ammonium nitrate. Photomicrographs of TP-41 Batch 1, Figure 13, were also made. The magnification of the film was X-250.

CONCLUSIONS

21. The choice of tests selected to be conducted on TP-41 were based on the most probable conditions that explosive components containing TP-41 would encounter. The results observed have in most cases been predictable. The data show the impact sensitivity of TP-41 to be equivalent to that of TNT. This is considered good, but TP-41 is not as predictable as TNT, having a drop height sensitivity range of 81-320 cm. The electrostatic spark sensitivity falls between that of PETN and tetryl which is tolerable. Cook-off temperature and vacuum stability data also show good characteristics when compared with the more common explosives such as lead azide, lead styphnate and PETN. However, some of the tests revealed that there are areas where serious problems, both from safety and reliability, can arise. It was demonstrated that the mixture could be initiated from an AC source with as little as 30 volts. The sensitivity of the mixture to a hot wire indicated that heating of the wire can on occasion cause ignition, which would involve safety. Again, slow heating of the wire also causes decomposition and a phase change in the mixture. This results in questionable reliability. The spark gap testing data appears to be acceptable. High static charges (10 to 20 thousand volts) can be built up on humans and materials. Since TP-41 is a conductive mix, consideration to safety must be given the component in the event a broken bridge-

wire or voltage breakdown between the lead wire and case should occur. Spark gap data showed ignitions as low as 3,000 volts. The propagation rate of TP-41 is relatively low. The ability of the mixture, in the item tested, to initiate an explosive such as CH-6 show it to be unreliable. The problems associated with moisture, loading density and, reproducibility of batch to batch lots can be overcome through proper techniques. The problems associated with temperature phase changes and compatability with other elements are more difficult to overcome. Based on the above observations it is recommended that this material not be used in electroexplosive devices.

TABLE 1

Impact Sensitivity Test Results for Various Batches of TP-41 and NOL TP-41

Material	Batch No.	N	Anvil	50% (cm) Firing Height	S (log units)
TP-41	1	10	Sandpaper	>320	--
TP-41	1	25	Sandpaper	114	0.11
TP-41	1	25	Sandpaper	164	0.13
TP-41	2	5	Sandpaper	>320	--
TP-41	2	6	Steel	180	0.17
TP-41	2	25	Sandpaper	81	0.16
TP-41	2	25	Steel	94	0.15
TP-41	2	25	Sandpaper	94	0.14
TP-41	2	25	Steel	96	0.12
TP-41	2	25	Sandpaper	76	0.17
TP-41	2	25	Steel	82	<0.03
TP-41	2	10	Sandpaper	>320	--
TP-41	2	10	Steel	>320	--
TP-41	2	15	Sandpaper	172	>0.50
TP-41	2	25	Sandpaper	77	0.12
TP-41	2	25	Sandpaper	320	0.10
TP-41	3	25	Sandpaper	111	0.23
TP-41	3	25	Sandpaper	120	0.06
NOL TP-41	1	25	Sandpaper	96	0.36
NOL TP-41	1	25	Steel	104	0.10
NOL TP-41	2	25	Sandpaper	85	0.12
NOL TP-41	2	25	Steel	120	0.25
NOL TP-41	2	25	Sandpaper	81	0.15
NOL TP-41	2	25	Steel	146	0.26
NOL TP-41	2	25	Sandpaper	97	0.23
NOL TP-41	2	25	Steel	143	0.09
NOL TP-41	2	10	Sandpaper	>320	
NOL TP-41	2	10	Steel	>320	
NOL TP-41	2	15	Sandpaper	134	0.08
PETN		25	Sandpaper	12	0.19
HMX		25	Sandpaper	25-31	0.08
Tetryl		25	Sandpaper	32	0.12
TNT		25	Sandpaper	187	0.14
Exp "D"		25	Sandpaper	235	0.14

N = number of trials
S = estimated standard deviation

TABLE 2

Impact Sensitivity of TP-41 as a Function of Moisture Content

Moisture Content (%)	Sample Size	50% Firing Height (cm)	S (log units)
0	25	161	0.4
0.5	25	236	0.47
1.0	25	227	0.5
1.5	25	285	0.11
2.0	10	>320	---
2.7	25	>320	---

TABLE 3

Results of Impact Sensitivity Testing of TP-41 and NOL TP-41 Containing Various Additives

Sample	Batch No.	Additive (1/2% by Wgt)	N	Anvil	50% Firing Height (cm)	S (log units)
TP-41	1	Cu	25	Sandpaper	317	0.16
	1	Zn	25	Sandpaper	132	0.20
	1	Mg	25	Sandpaper	249	>0.50
	1	Mg	10	Sandpaper	>320	--
	1	Sn	25	Sandpaper	147	0.24
	1	Ni	25	Sandpaper	>320	--
	1	Fe	25	Sandpaper	291	0.23
	2	Cu	25	Sandpaper	259	0.26
	2	Mg	25	Sandpaper	133	0.30
	2	Zn	25	Sandpaper	114	0.25
	2	Benzoic Acid	25	Sandpaper	146	0.21
	2	Carnauba Wax	25	Sandpaper	99	0.21
	2	Benzoic Acid	25	Steel	129	> .50
	2	Carnauba Wax	25	Steel	107	> .50
NOL TP-41	1	Carborundum	25	Sandpaper	88.5	0.07
	1	SiO_2	25	Sandpaper	115.7	0.26
	1	ZrO_2	25	Sandpaper	125	0.18
	2	Cu	10	Sandpaper	>320	--
	2	Mg	25	Sandpaper	296	0.27
	2	Zn	25	Sandpaper	157	0.39
	2	Benzoic Acid	25	Sandpaper	214	0.25
	2	Carnauba Wax	25	Steel	104	0.13
	2	Benzoic Acid	25	Steel	264	0.23
	2	Carnauba Wax	25	Steel	125	0.15

N = number of trials
S = estimated standard deviation

TABLE 4

Results of Static Spark Sensitivity Testing
(Maximum No-Fire Energy at a Given Capacitance)

	Sample Size	Capacitance (microfarads) 4.0	2.0	1.0	0.1	0.05	0.01
TP-41							
Potential	15	398	631	1000	1590	2510	6310
Energy		0.32	0.39	0.50	0.13	0.16	0.20
TP-41 + 0.5% COPPER							
Potential	10	500	631	794	1590	2000	5000
Energy		0.50	0.39	0.32	0.13	0.10	0.13
TP-41 + 0.5% ZINC							
Potential	10	500	500	794	1590	2000	6310
Energy		0.50	0.25	0.32	0.13	0.10	0.20
TP-41 + 0.5% MAGNESIUM							
Potential	10	631	631	794	1590	2510	5000
Energy		0.78	0.39	0.32	0.13	0.16	0.13
TP-41 + 0.5% TIN							
Potential	10	500	500	794	1590	2000	5000
Energy		0.50	0.25	0.32	0.13	0.10	0.13
TP-41 + 0.5% NICKEL							
Potential	10	794	631	794	1590	2000	3980
Energy		1.28	0.39	0.32	0.13	0.10	0.08
TP-41 + 0.5% IRON							
Potential	10	631	631	794	1590	2510	5000
Energy		0.78	0.39	0.32	0.13	0.16	0.13

Potential in volts.
Energy in Joules.

TABLE 5

Results of Static Spark Sensitivity Testing for TP-41 Batch 1
(Percent Fires at Constant Capacitance and Voltage)

Capacitance (microfarads)	Potential (volts)	Energy (joules)	Fires (percent)
2.0	750	0.56	20
	1000	1.00	20
	1250	1.56	30
	1500	2.25	50
	2000	4.00	30
	2500	6.25	70
	2750	7.56	90
	3000	9.00	100
1.0	1500	1.13	50
	2000	2.00	60
	2500	3.13	70
	3000	4.50	70
	3500	6.13	80
	4000	8.00	100
	4250	9.03	90
	4500	10.13	100
	4750	11.20	90
	5000	12.50	90
	5500	15.13	80
	6000	18.00	100
	6250	19.53	100
	6500	21.13	100
0.1	1500	0.11	0
	2000	0.20	0
	3000	0.45	30
	4000	0.80	50
	5000	1.25+	80
	5750	1.65	80
	6000	1.80	90
	6250	2.11	50
	7250*	2.63	70

SAMPLE SIZE - 10

*Limit of test apparatus

TABLE 6

Spark Gap Sensitivity
TF-41 Batch 2

Gap(mils)	Potential (KV)									
	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
5									0/5	2/9
10								0/5	1/4	3/5
15								0/5	3/5	3/5
20					0/5	1/5	2/2	3/4	2/3	8/10
30						0/10	6/10	7/8	10/10	5/5
40			0/5	1/4	1/2	1/2	1/2	1/2	7/10	10/10
50	0/8	1/2	1/2	5/5	4/4	5/5	5/5			5/5
60	0/5	1/2	1/2	1/2	6/7	9/10	9/10	10/10		

Ratio of fires to the number tested

TABLE 7

RESULTS OF EXPLODING BRIDGE WIRE TESTING OF TP-41 AND TP-41 MIXTURES

		TP-41 Batch 2		TP-41 Batch 2 Plus Additives		
Potential (volts)	Energy (Joules)	0.65 g/cm^3 Loading Density	1.0 g/cm^3	0.5% Cu 1.0 g/cm^3	0.5% Mg 1.0 g/cm^3	0.5% Zn 1.0 g/cm^3
3000	4.5			5/5		
2500	3.1			2/5		5/5
2000	2.0	10/10		4/5	5/5	4/5
1500	1.1	8/10		3/5	4/5	5/5
1000	0.5	2/10	5/5	3/5	3/5	4/5
500	0.12	0/10	1/5	0/5	0/5	0/5
250	0.031		0/5			

		NOL TP-41				
Potential (volts)	Energy (Joules)	0.65 g/cm^3 Loading Density	1.0 g/cm^3	0.5% Cu 1.0 g/cm^3	0.5% Mg 1.0 g/cm^3	0.5% Zn 1.0 g/cm^3
5000	12.5			5/5		
4500	10.1			4/5		
4000	8.0			4/5	5/5	5/5
3500	6.1		5/5	4/5	3/5	1/5
3000	4.5		4/5	2/5	2/5	4/5
2500	3.1	10/10	2/5	2/5	2/5	4/5
2000	2.0	5/10	2/5	1/5	2/5	0/5
1500	1.1	0/10	0/5	0/5	0/5	
1000	0.5					
500	0.12					
250	0.031					

1. Bridgewire - 1 mil Tophet "C"

TABLE 8

CHEMICAL ANALYSIS OF TP-41 BATCH 2

Based on original sample:		
Moisture		0.05%
Petroleum ether extract		0.15%
Water insoluble (chiefly aluminum)		20.05%
Water soluble (by difference)		79.75%
Acid insoluble in water insoluble		0.40%
Carbon in acid insoluble		0.24%
Additional loss on ignition, acid insoluble		0.05%
Silica in acid insoluble		0.11%
Iron in acid soluble		0.08%
Ammonium nitrate in water soluble		79.10%
Based on water insoluble:		
Petroleum ether extract		0.66%
Acid insoluble (dried at 105°C)		1.98%
Carbon in acid insoluble		1.18%
Additional loss of ignition, acid insoluble		0.25%
Silica in acid insoluble		0.55%
Iron in acid soluble		0.40%
Aluminum by difference		96.96%
Based on water soluble:		
Ammonium nitrate, Kjeldahl assay		99.18%
Total solics, vacuum dried at 50°C		99.68%
Residue on ignition		0.15%
Chloride	Less than	0.01%
Sulfate	" "	0.01%
Iron	" "	0.01%
Aluminum	" "	0.01%
Heavy metals	" "	0.01%

TABLE 9

Particle Size Analysis of TP-41, Batch 1

Cell Size Diameters (microns)		Count	Percent
0.8	=	47	18.1
8-16	=	102	39.4
16-24	=	53	20.5
24-32	=	26	10.0
32-40	=	20	7.7
40-48	=	6	2.3
48-56	=	3	1.2
56-64	=	1	0.4
64-72	=	1	0.4

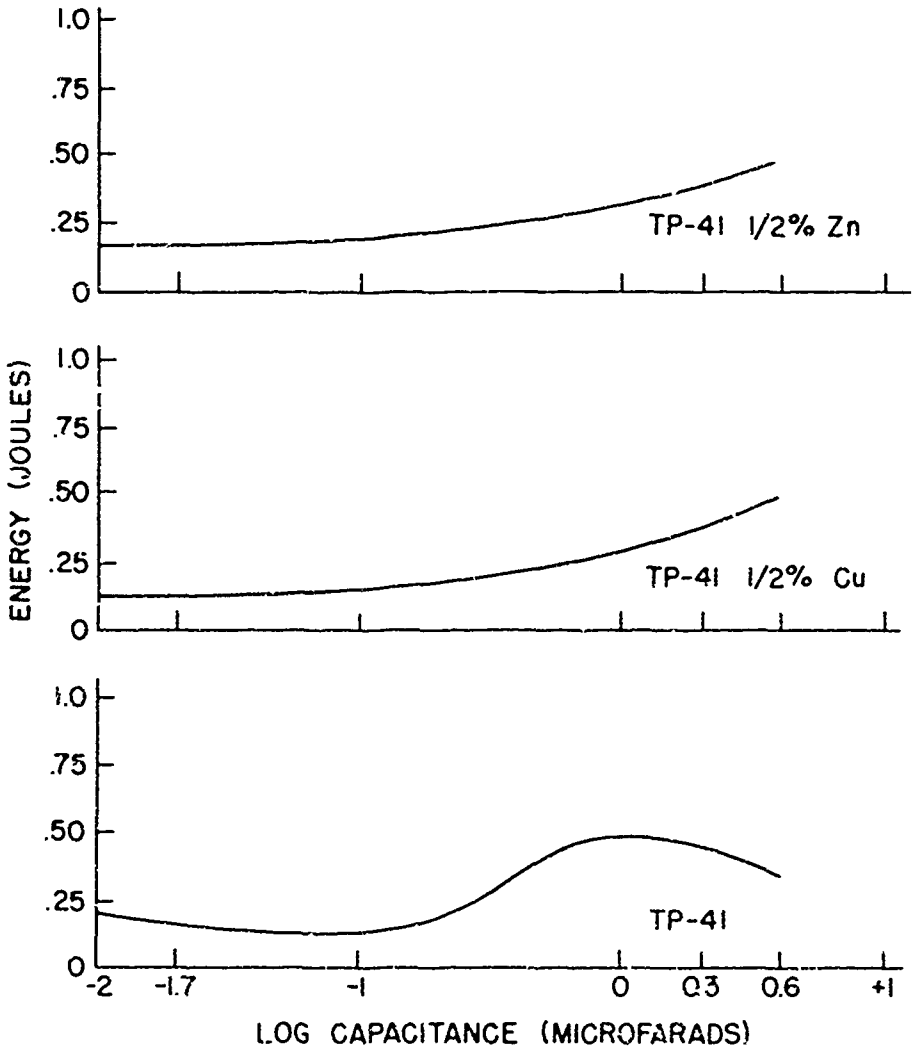


FIG. 1 MAXIMUM ELECTROSTATIC ENERGY FOR WHICH NO IGNITIONS OCCUR

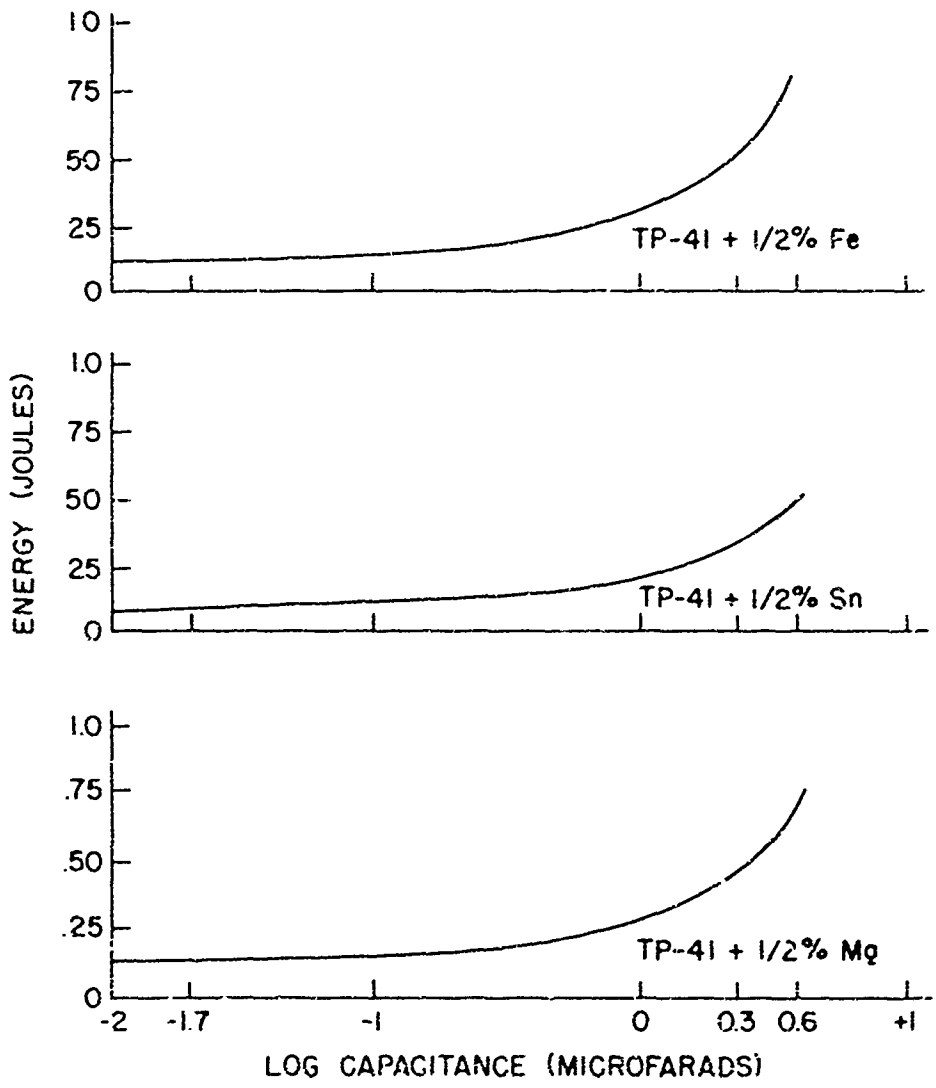


FIG. 2 MAXIMUM ENERGY VERSUS CAPACITANCE FOR WHICH NO IGNITIONS OCCUR

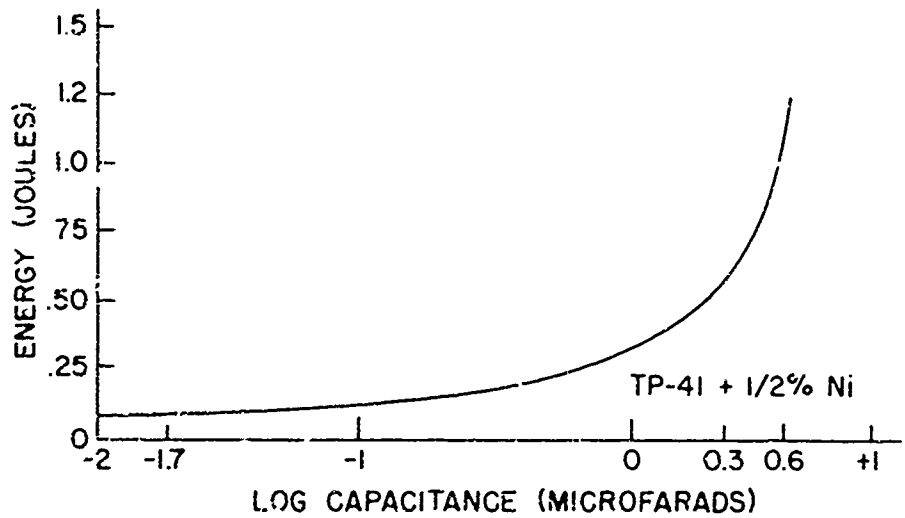


FIG. 3 MAXIMUM ELECTROSTATIC ENERGY FOR TP-41 + 1/2% Ni FOR WHICH NO IGNITIONS OCCUR

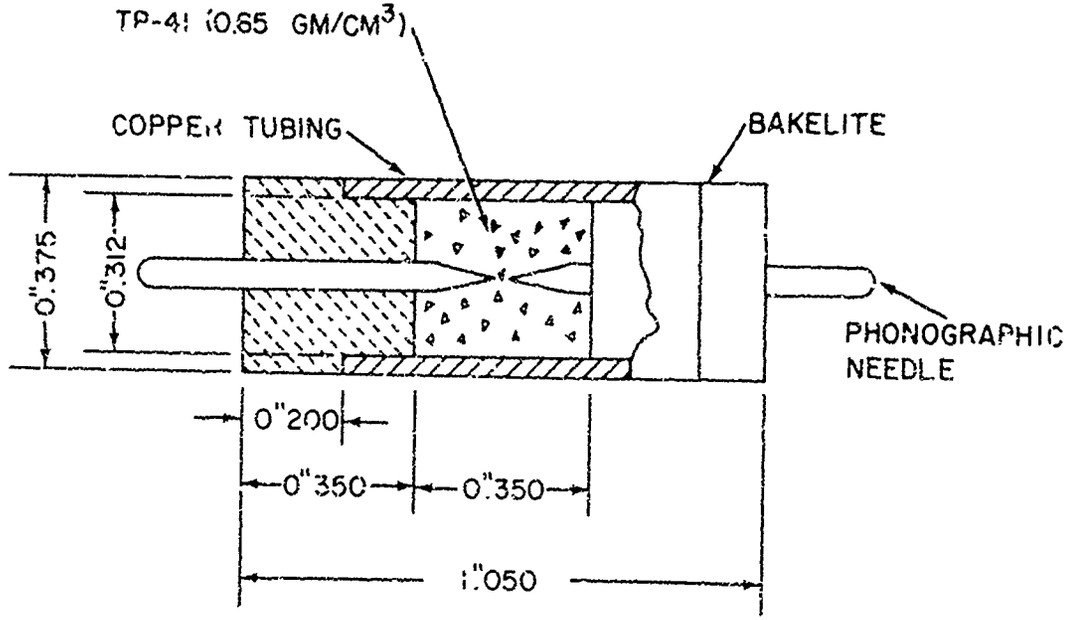


FIG. 4 SPARK GAP TEST VEHICLE

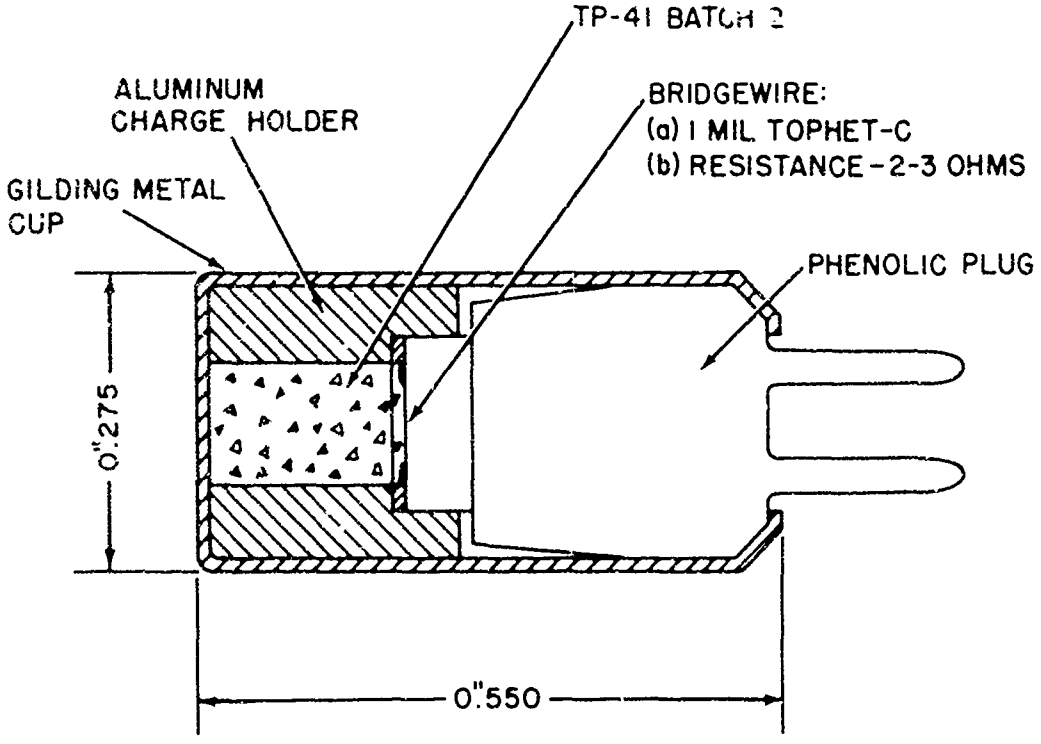


FIG. 5 EXPLODED BRIDGEWIRE TEST VEHICLE

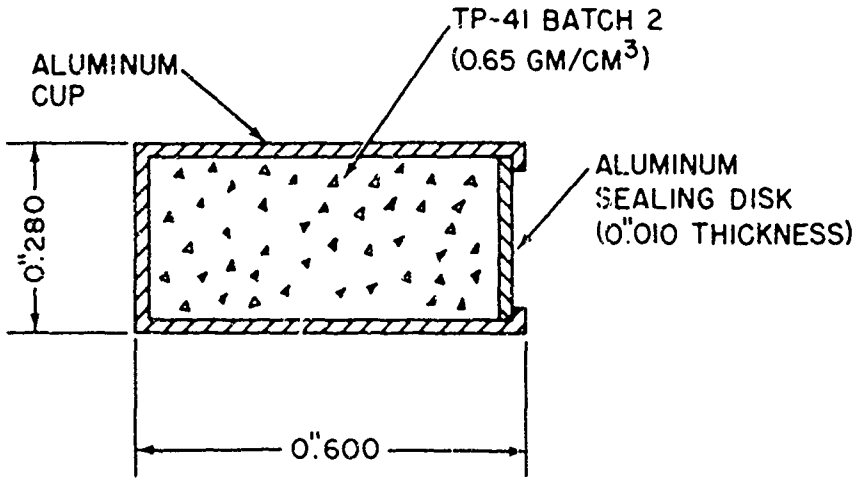


FIG. 6 LOADED TEST VEHICLE USED IN "COOK-OFF" DETERMINATIONS

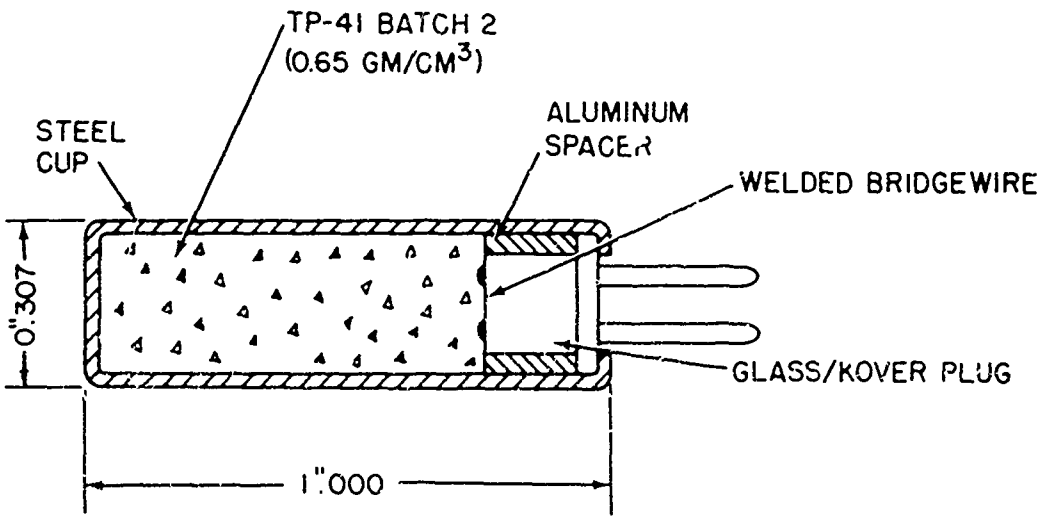


FIG 7 TEST VEHICLE USED TO OBTAIN DATA ON "COOK-OFF" AND SENSITIVITY OF MOLTEN TP-41

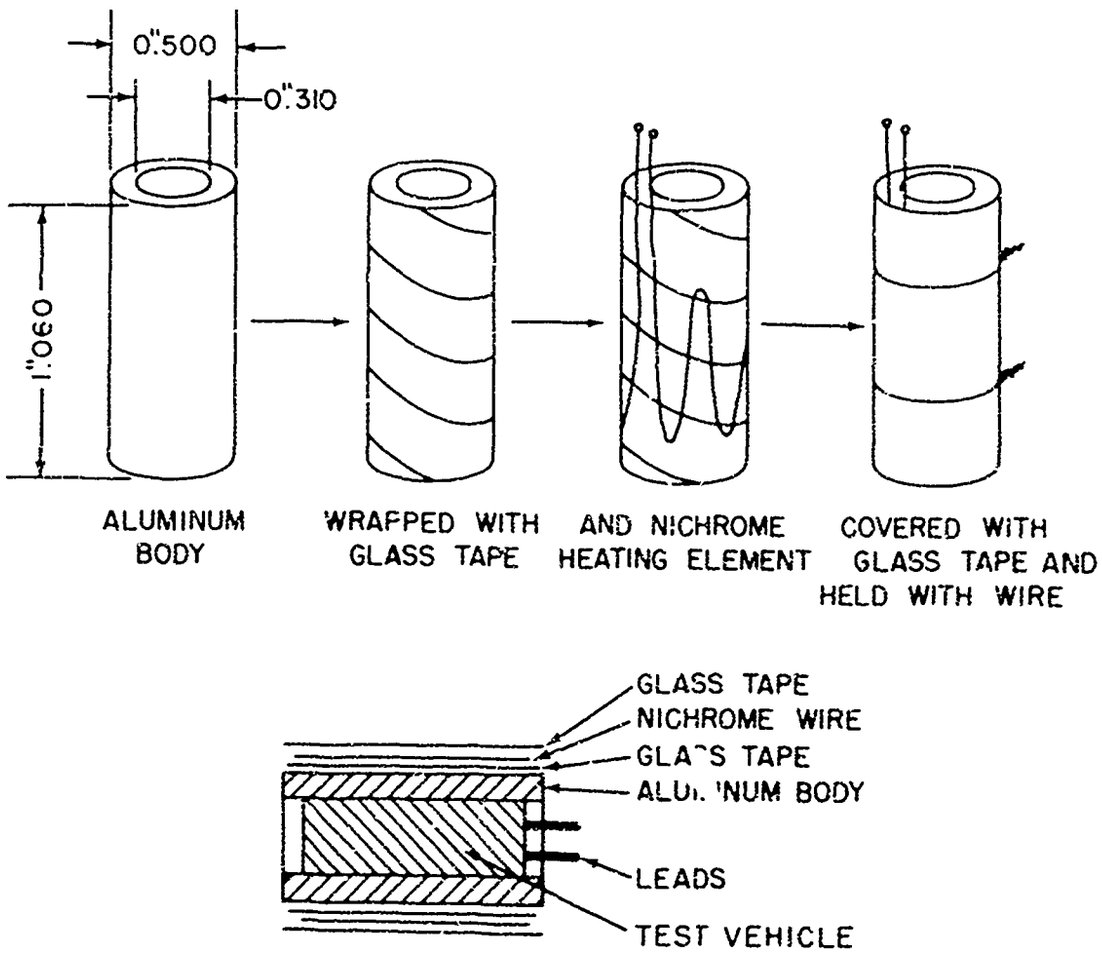


FIG. 8 PROCEDURE FOR PREPARATION OF FURNACE

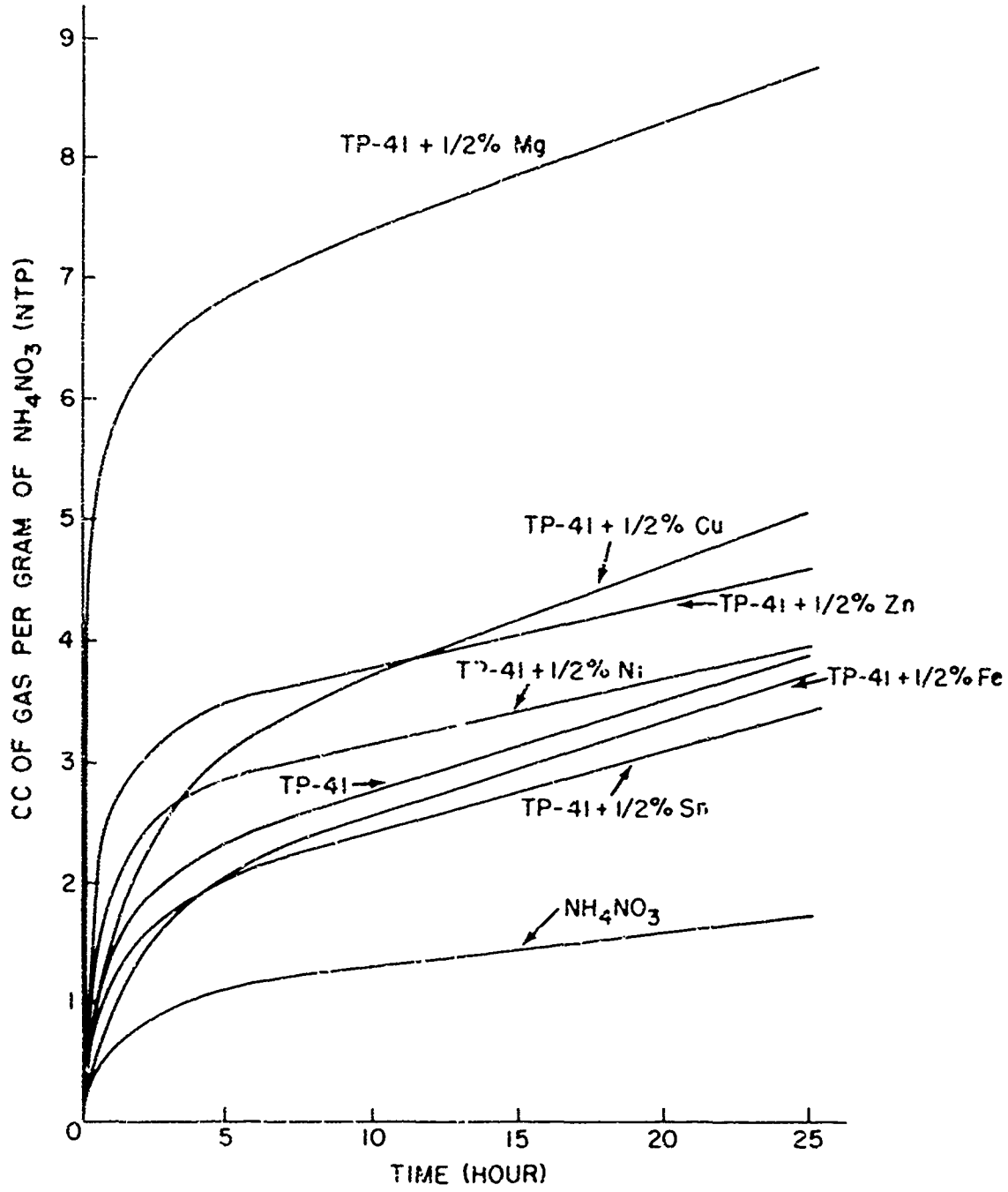


FIG. 9 THERMAL STABILITY TESTS AT 150° C

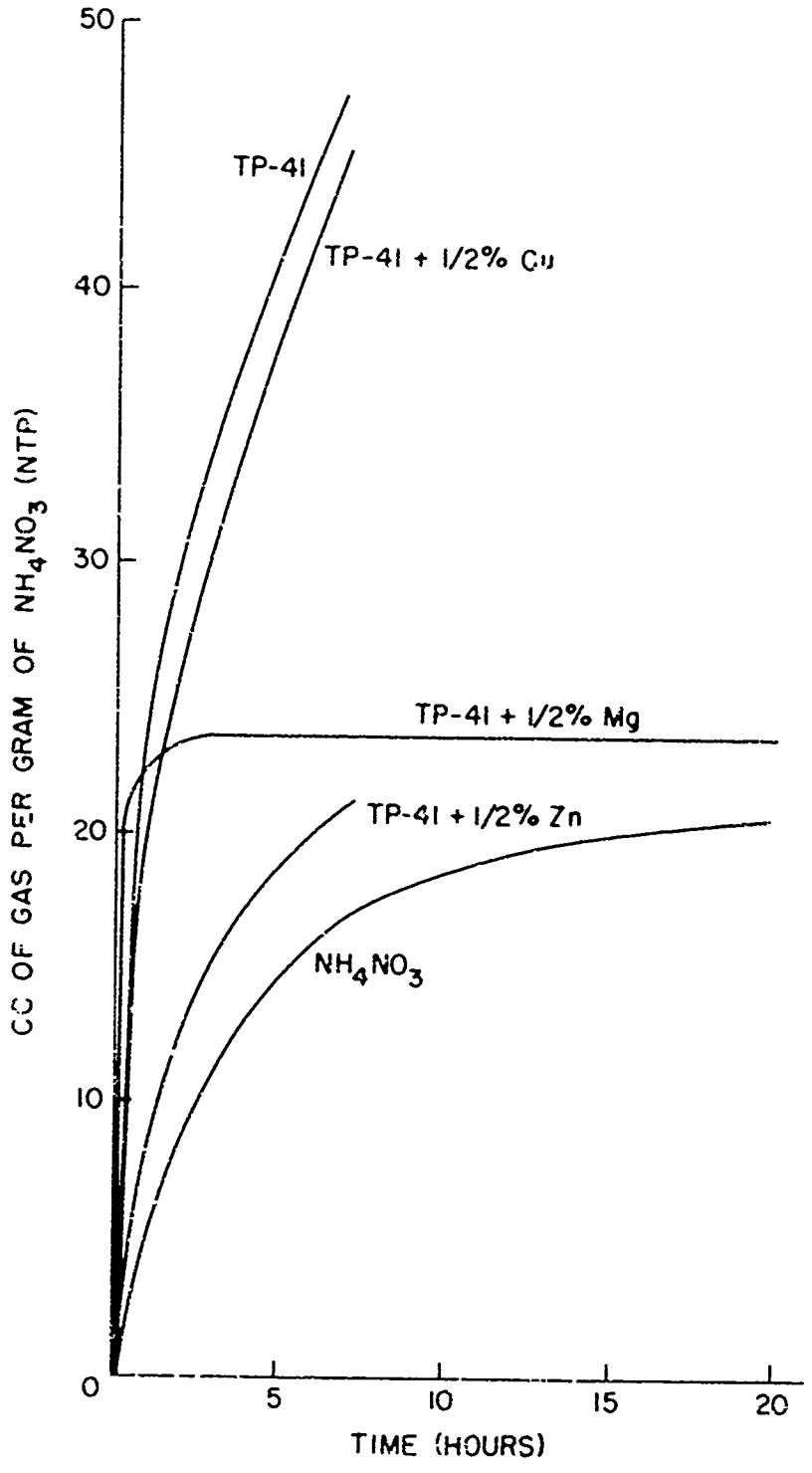


FIG 10 THERMAL STABILITY TESTS AT 200° C

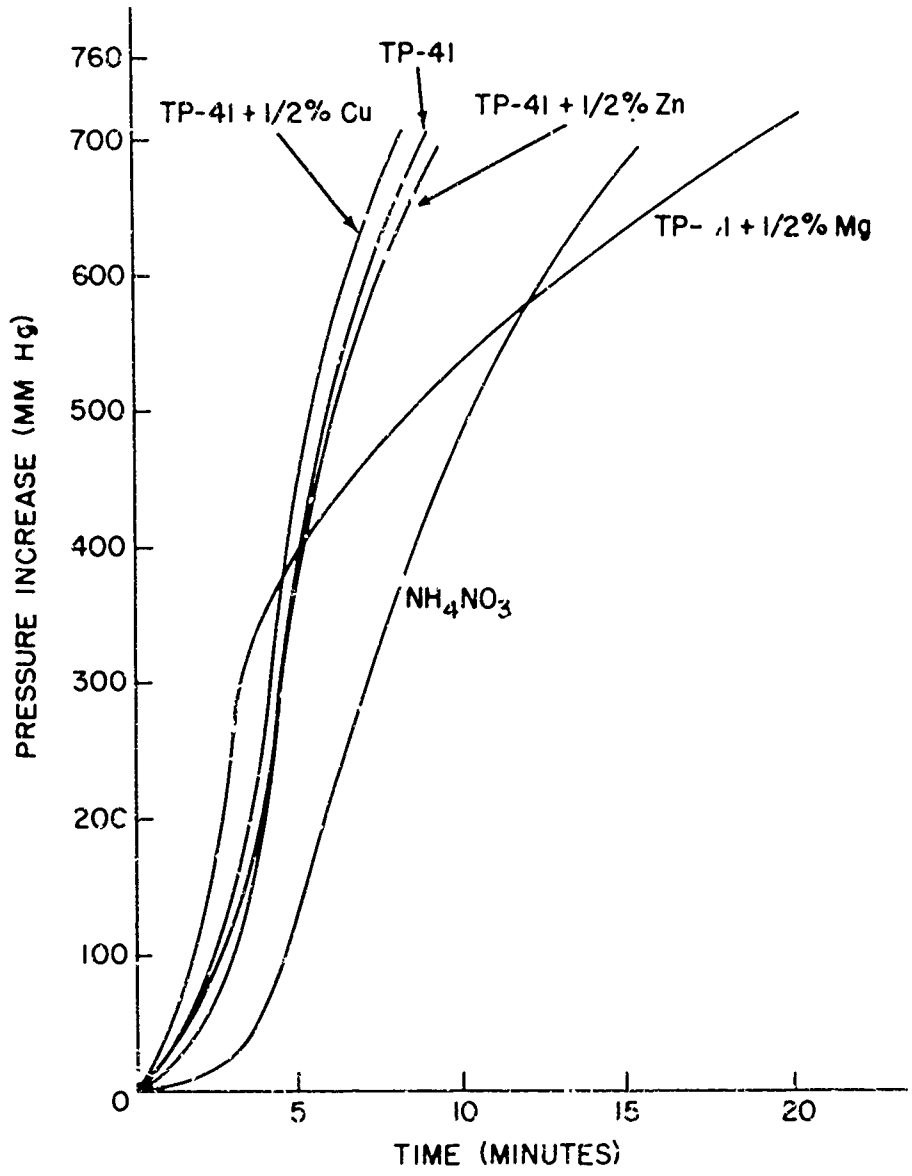


FIG. 11 THERMAL STABILITY TESTS AT 250° C

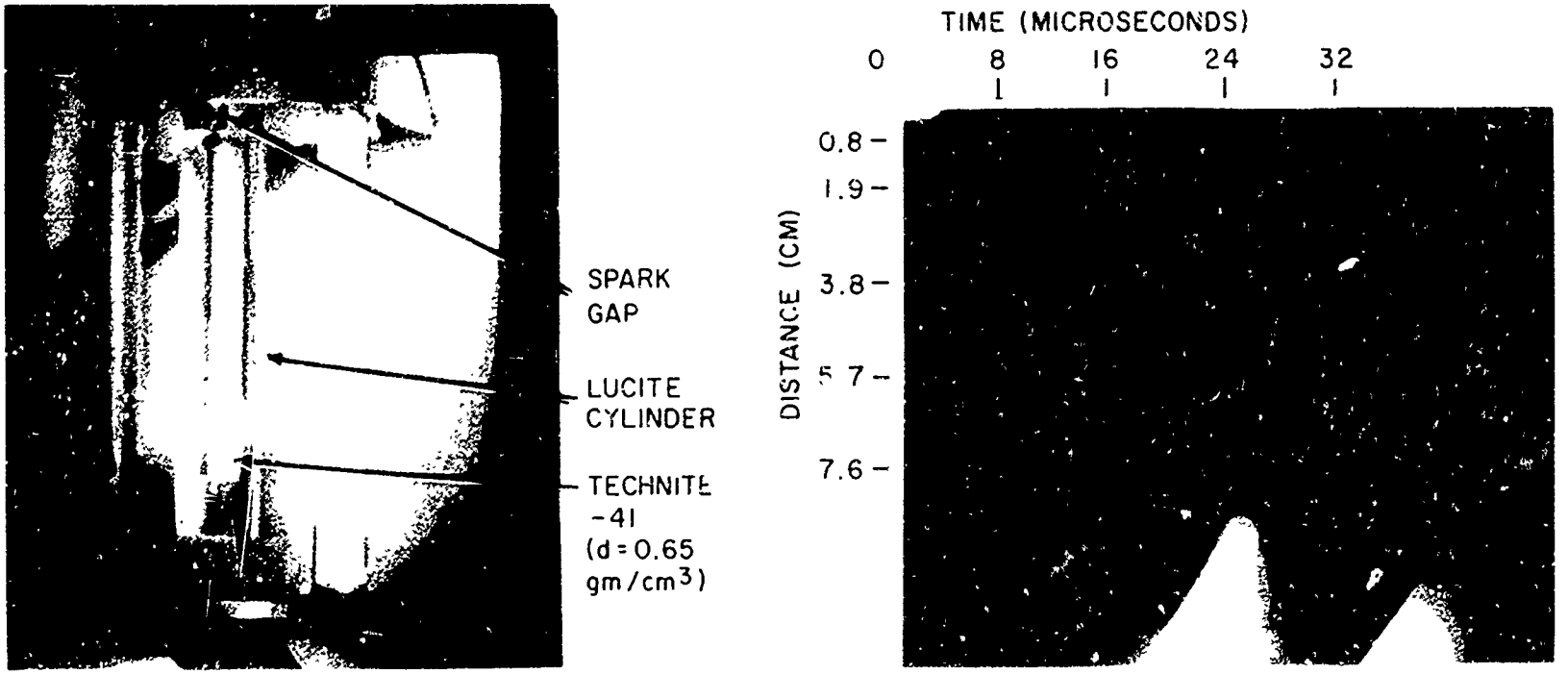
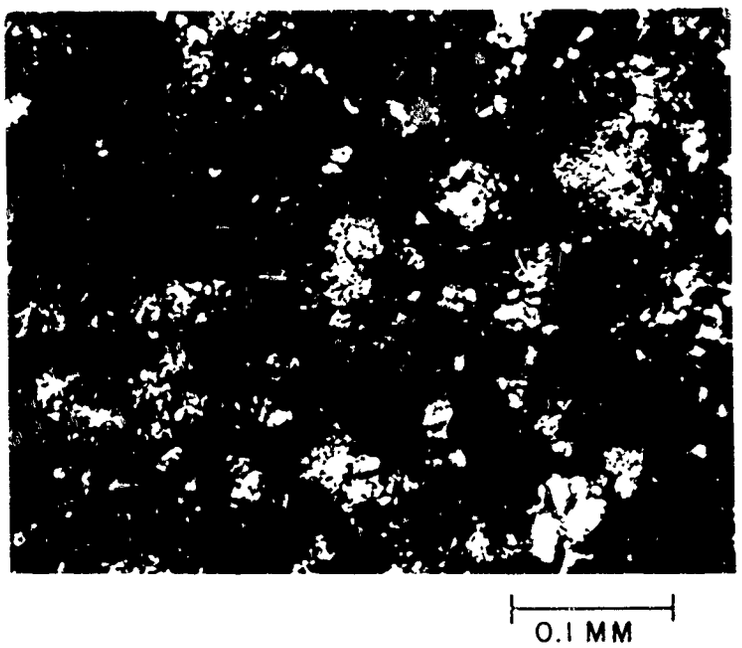


FIG 12 SMEAR CAMERA RECORD OF TECHNITE - 41



2.5 CM = 0.1 MM

FIG 13 PHOTOMICROGRAPHS OF TP-41 BATCH 1

APPENDIX A

Description of Impurities Used

Sample Material	Manufacturer	Remarks
Magnesium	---	Grade A, Type 1 Gram 10 Spec -M-382(200 Mesh)
Nickel (99+%)	Varlacoid Chem Co	(-325 Mesh)
Tin	Varlacoid Chem. Co	(-325 Mesh)
Copper Flakes	---	(-325 Mesh)
Zinc Dust	---	TR-1871 Sample No. 44
Carbonyl Iron	---	Grade SF 1-5 microns
Carborendum	Fisher Scientific Co	No. F Powder about 250 Mesh
Ground Glass	Corning Glass Works	Glass No. 1720 - 100 Mesh
(Aluminum-Silicate)		
C. P. Zironium Oxide	Titanium Alloy Mfg Co	Lot 51 about 100 Mesh
Carnauba Wax	---	---
Benzoic Acid	---	---

APPENDIX B

Mixing Procedure Used in Preparing NOL TP-41 Batch 1

(a) Reagent grade, granular ammonium nitrate (particle size thru - 325 Mesh) was used.

(b) Flake Aluminum from Metals Disintegrating Co. (particle size 85% thru -325 Mesh) was used.

(c) The proper proportion, 80% ammonium nitrate, and 20% aluminum were dry mixed by tumbling in a metal can for 4 hours.

(d) At the end of tumbling, this mix was dried for 16 hours at 100° F in a vacuum oven.

Mixing Procedure Used in Preparing NOL TP-41 Batch 2

(a) Reagent grade, granular ammonium nitrate was dried for 24 hours at 150°F.

(b) After drying, the ammonium nitrate was milled for 2 hours in a quart size ball mill using 33 steel balls approximately 3/4 inch diameter. The material was then screened and proportioned as follows:

through 60 on 150 mesh - 10%

through 150 on 200 mesh - 55%

through 200 mesh - 35%

(c) The material was then dried for 16 hours in a vacuum oven at 170°F.

(d) The aluminum powder used was obtained from the Keade Manufacturing Company, grade: Dark Pyro, date 4 Feb 1960.

(e) The ammonium nitrate and aluminum were combined and rotated in a one quart size, twin sleeve blender for two hours at 30 R.P.M. Eight steel balls approximately 3/4-inch in diameter were placed in the blender during this operation.

(f) The mix was transferred to a one gallon can containing steel balls and blending continued for six more hours by rotating the cans at 30 R.P.M.

(g) The mix was passed through a No. 10 sieve, dried in a vacuum oven for two hours at 150°F, and then stored in a disiccator.